

SPECIFICATION

TITLE OF THE INVENTION

SEMICONDUCTOR LASER DEVICE

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a semiconductor laser device with a dielectric multilayer film.

10 2. Description of the Related Art

Generally, a semiconductor laser has resonator end faces formed by wafer cleavage, and dielectric films are formed on the resonator end faces. A desired reflectance of each end face can be controlled by arbitrarily selecting species, film thickness and number of layers of the dielectric film on the end face.

Such a reflective film requires not only characteristics of arbitrarily controllable reflectance but also of high tolerance to degrading due to catastrophic optical damage (COD). The COD degradation means that the film on the end face of a laser device is heated up by absorbing laser light and then melted down as temperature rises, resulting in destruction of the end face.

When forming a reflective film with 40% or more of reflectance, for example, a dielectric multilayer film with

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a low refractive index film and a high refractive index film laminated alternately is employed in general. The related prior arts are listed as follows:

[Document 1] Japanese Patent Unexamined Publications
5 (koukai): JP-H10-247756 (1998), A

[Document 2] Japanese Patent Unexamined Publications
(koukai): JP-2001-267677, A

[Document 3] Japanese Patent Unexamined Publications
(koukai): JP-2002-305348, A

10 For example, the document 2 (JP-2001-267677) employs a multilayer reflective film of five layers including a Al_2O_3 film and a Si film containing oxygen for the high reflective film on the rear end face of a semiconductor laser, in which introduction of oxygen into a deposition
15 process of Si film enables an extinction coefficient of Si to decrease, thereby preventing the COD degradation. However, with laser oscillation wavelength shortened and laser power heightened, the Si film is likely to have an optical absorption coefficient, which may exceed a certain
20 limit to cause the COD degradation.

Meanwhile, the document 1 (JP-H10-247756) employs a multilayer film of titanium oxide (TiO_2) and silicon oxide (SiO_2) for the reflective film on the optical exit face of a semiconductor laser to improve the COD level. However,
25 titanium oxide has low thermal stability in emission and is

likely to age. Therefore, the reflectance may change because of variations of thickness and refractive index of the film, finally the COD degradation will occur.

Moreover, the document 3 (JP-2002-305348) employs a
5 multilayer film of niobium oxide (Nb_2O_3) and silicon oxide (SiO_2) for the reflective film on the end face of the resonator of a semiconductor laser with an oscillation wavelength of 400nm.

In conventional semiconductor lasers, a multilayer
10 reflective film including a high refractive index film, such as Si film, titanium oxide (TiO_2) film, is studied. However, with laser power further heightened in the future, temperature of the laser end face will increasingly rise in emission. Therefore, the COD degradation and the aging,
15 such as change of reflectance due to variations of thickness and refractive index, are concerned.

SUMMARY OF THE INVENTION

The purpose of the present invention is to provide a
20 semiconductor laser device with a dielectric multilayer film, which is configured of a material which has an optical absorption coefficient smaller than that of silicon (Si) film and thermal stability in emission superior to that of titanium oxide (TiO_2) film to remarkably improve
25 the COD degradation level.

A semiconductor laser device according to the present invention includes:

5 a dielectric multilayer film with a reflectance of 40% or more, formed on at least one of optical exit faces of a laser chip;

wherein the dielectric multilayer film includes a dielectric film of tantalum oxide.

10 In the present invention, the dielectric multilayer film may include a dielectric film of aluminum oxide and the dielectric film of tantalum oxide.

15 Furthermore, the dielectric multilayer film may include a dielectric film of aluminum oxide for a film in contact with the laser chip, and may further include a dielectric film of silicon oxide and the dielectric film of tantalum oxide.

20 According to the present invention, when the dielectric multilayer film is configured using the tantalum oxide (Ta_2O_5) film, the changes of both refractive index and film thickness are kept small even if temperature of the dielectric multilayer film rises by light absorption, thereby remarkably improving deterioration level of the dielectric multilayer film due to aging and COD.

BRIEF DESCRIPTION OF THE DRAWINGS

25 Fig.1A is a structural drawing showing a first

embodiment of the present invention. Fig.1B is an enlarged view showing the configuration of a high reflective film. Fig.1C is a graph showing wavelength dependency of reflectance of the high reflective film.

5 Fig.2A and Fig.2B are graphs showing temperature dependencies of both refractive index and film thickness of tantalum oxide (Ta_2O_5) and titanium oxide (TiO_2) films.

Fig.3A is a structural drawing showing a second embodiment of the present invention. Fig.3B is an enlarged
10 view showing the configuration of another high reflective film. Fig.3C is a graph showing wavelength dependency of reflectance of the high reflective film.

Fig.4 is a graph showing an example of optical output characteristics versus driving current of a semiconductor
15 laser.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This application is based on an application No. 2003-118151 filed April 23, 2003 in Japan, the disclosure of
20 which is incorporated herein by reference.

Hereinafter, preferred embodiments will be described with reference to drawings.

Embodiment 1

Fig.1A is a structural drawing showing a first
25 embodiment of the present invention, which illustrates a

perpendicular cross section along an optical axis. A laser chip includes a semiconductor substrate 1 of ,e.g. GaAs, an active layer 2, cladding layers 3 formed on both upper side and lower side of the active layer 2, and electrodes 4
5 formed on both upper side and lower side of the cladding layers 3.

A laser semiconductor device includes the above laser chip, a low reflective film 9 formed on the front end face of the laser, and a high reflective film 10 formed on the
10 rear end face of the laser.

Typically, the low reflective film 9 is so configured as to have a reflectance of 15% or less and the high reflective film 10 is so configured as to have a reflectance of 40% or more.

15 The low and high reflective films 9 and 10 can be formed using deposition process, such as vapor deposition, spatter, and CVD (chemical vapor deposition). A optical resonator is constituted between the front and rear end faces of the laser. Most of laser light which oscillates
20 in the active layer 2 is emitted from the low reflective film 9 as output light L_o and part of laser light is also emitted from the high reflective film 10.

Fig.1B is an enlarged view showing the configuration of the high reflective film 10. The high reflective film
25 10 is configured of, in sequence from the side contact with

the laser chip, a dielectric film 11 having a refractive index n_{11} and a thickness d_{11} , a dielectric film 12 having a refractive index n_{12} and a thickness d_{12} , a dielectric film 13 having a refractive index n_{13} and a thickness d_{13} ,
5 a dielectric film 14 having a refractive index n_{14} and a thickness d_{14} , a dielectric film 15 having a refractive index n_{15} and a thickness d_{15} , a dielectric film 16 having a refractive index n_{16} and a thickness d_{16} , a dielectric film 17 having a refractive index n_{17} and a thickness d_{17} ,
10 a dielectric film 18 having a refractive index n_{18} and a thickness d_{18} , and a dielectric film 19 having a refractive index n_{19} and a thickness d_{19} .

A typical dielectric multilayer film is configured so that a dielectric film having a high refractive index and a
15 dielectric film having a low refractive index are alternately and repeatedly laminated. Thickness of each dielectric film is typically designed to be an integral multiplication of quarter of the oscillation wavelength λ , i.e., $\lambda/4$ in terms of optical length. Therefore, a
20 appropriate film thickness is adjusted according to the refractive index of the dielectric film.

In this embodiment, the high reflective film 10 includes the dielectric film of tantalum oxide (Ta_2O_5) and the dielectric film of aluminum oxide (Al_2O_3). Tantalum
25 oxide has characteristics of small changes of both

refractive index and film thickness even if temperature is rising by heating, as described later, which is suitable for the dielectric multilayer film.

Next, a specific configuration of the high reflective film 10 will be described hereinafter. Here, the high reflective film 10 formed on a red semiconductor laser with oscillation wavelength $\lambda=660\text{nm}$ will be exemplified. The equivalent refractive index of the laser chip is 3.817.

As shown Fig.1B, the dielectric film 11, i.e., the first layer in contact with the laser chip is formed of aluminum oxide (Al_2O_3) with refractive index $n_{11} = 1.641$, thickness d_{11} of which is designed to be 100.5nm equivalent to $\lambda/4$ in terms of optical length.

The dielectric film 12, i.e., the second layer is formed of tantalum oxide (Ta_2O_5) with refractive index $n_{12} = 2.031$, thickness d_{12} of which is designed to be 81.2nm equivalent to $\lambda/4$ in terms of optical length.

The dielectric film 13, i.e., the third layer is formed of aluminum oxide (Al_2O_3) with refractive index $n_{13} = 1.641$, thickness d_{13} of which is designed to be 100.5nm equivalent to $\lambda/4$ in terms of optical length.

The dielectric film 14, i.e., the fourth layer is formed of tantalum oxide (Ta_2O_5) with refractive index $n_{14} = 2.031$, thickness d_{14} of which is designed to be 81.2nm equivalent to $\lambda/4$ in terms of optical length.

The dielectric film 15, i.e., the fifth layer is formed of aluminum oxide (Al_2O_3) with refractive index $n_{15} = 1.641$, thickness d_{15} of which is designed to be 100.5nm equivalent to $\lambda/4$ in terms of optical length.

5 The dielectric film 16, i.e., the sixth layer is formed of tantalum oxide (Ta_2O_5) with refractive index $n_{16} = 2.031$, thickness d_{16} of which is designed to be 81.2nm equivalent to $\lambda/4$ in terms of optical length.

10 The dielectric film 17, i.e., the seventh layer is formed of aluminum oxide (Al_2O_3) with refractive index $n_{17} = 1.641$, thickness d_{17} of which is designed to be 100.5nm equivalent to $\lambda/4$ in terms of optical length.

15 The dielectric film 18, i.e., the eighth layer is formed of tantalum oxide (Ta_2O_5) with refractive index $n_{18} = 2.031$, thickness d_{18} of which is designed to be 81.2nm equivalent to $\lambda/4$ in terms of optical length.

20 The dielectric film 19, i.e., the ninth layer is formed of aluminum oxide (Al_2O_3) with refractive index $n_{19} = 1.641$, thickness d_{19} of which is designed to be 201.0nm equivalent to $\lambda/2$ in terms of optical length.

Fig.1C is a graph showing wavelength dependency of reflectance of the high reflective film 10 having the above configuration. This graph shows a reflectance of about 83% at the center wavelength $\lambda=660\text{nm}$, where the change of reflectance is small as against the change of oscillation

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wavelength. Therefore, it can be seen that the high reflective film 10 with the above configuration has a stable reflectance even if the oscillation wavelength of the laser varies.

5 Fig.2A and Fig.2B are graphs showing temperature dependencies of both refractive index and film thickness of tantalum oxide (Ta_2O_5) and titanium oxide (TiO_2) films, where the changes of both refractive index and film thickness at a heating temperature of about 400 degree-C are illustrated in percentage terms using reference values
10 of 100% for the refractive index and the film thickness at a heating temperature of about 110 degree-C.

The graphs show that refractive index of the titanium oxide film increases by +2.18% about 400 degree-C, while
15 refractive index of the tantalum oxide film is suppressed by an increment of +0.94%, in addition, film thickness of the titanium oxide film decreases by -1.95% about 400 degree-C, while film thickness of the tantalum oxide film is suppressed by a decrement of -0.26%. It can be seen
20 from the graphs that the tantalum oxide film is superior in thermal stability to the titanium oxide film.

Accordingly, when the laser chip emits laser light of high power and temperature of the high reflective film 10 rises by light absorption, the existence of titanium oxide
25 (TiO_2) film will encourage the changes of both refractive

index and film thickness. Therefore, as laser light is repeatedly turned on and off, the high reflective film 10 is likely to be debased by aging, resulting in the COD degradation.

5 On the other hand, when the high reflective film 10 is formed using the tantalum oxide (Ta_2O_5) film, the changes of both refractive index and film thickness are kept small even if temperature of the high reflective film 10 rises by light absorption, thereby preventing the high reflective
10 film 10 from deteriorating by aging and COD.

 Incidentally, the above description exemplifies the high reflective film 10 which includes the multilayered films having four cycles using the repetitious unit of both the single tantalum oxide film for the high refractive
15 index film and the single aluminum oxide film for the low refractive index film, and the additive aluminum oxide film for the low refractive index film exposed to the atmosphere. The high reflective film 10 may be configured of one to three cycles or five cycles or more using the repetitious
20 unit of both the single tantalum oxide film and the single aluminum oxide film to control a desired reflectance. Furthermore, when shifting the center wavelength of the reflectance characteristic from 660nm, measures can be taken by converting the film thickness of each dielectric
25 film to another film thickness in terms of optical length.

Embodiment 2

Fig.3A is a structural drawing showing a second embodiment of the present invention, which illustrates a perpendicular cross section along an optical axis. A laser chip includes a semiconductor substrate 1 of ,e.g. GaAs, an active layer 2, cladding layers 3 formed on both upper side and lower side of the active layer 2, and electrodes 4 formed on both upper side and lower side of the cladding layers 3.

A laser semiconductor device includes the above laser chip, a low reflective film 9 formed on the front end face of the laser, and a high reflective film 20 formed on the rear end face of the laser.

Typically, the low reflective film 9 is so configured as to have a reflectance of 15% or less and the high reflective film 20 is so configured as to have a reflectance of 40% or more.

The low and high reflective films 9 and 20 can be formed using deposition process, such as vapor deposition, spatter, and CVD (chemical vapor deposition). A optical resonator is constituted between the front and rear end faces of the laser. Most of laser light which oscillates in the active layer 2 is emitted from the low reflective film 9 as output light L_o and part of laser light is also

emitted from the high reflective film 20.

Fig.3B is an enlarged view showing the configuration of the high reflective film 20. The high reflective film 20 is configured of, in sequence from the side contact with the laser chip, a dielectric film 21 having a refractive index n_{21} and a thickness d_{21} , a dielectric film 22 having a refractive index n_{22} and a thickness d_{22} , a dielectric film 23 having a refractive index n_{23} and a thickness d_{23} , a dielectric film 24 having a refractive index n_{24} and a thickness d_{24} , a dielectric film 25 having a refractive index n_{25} and a thickness d_{25} , a dielectric film 26 having a refractive index n_{26} and a thickness d_{26} , a dielectric film 27 having a refractive index n_{27} and a thickness d_{27} , and a dielectric film 28 having a refractive index n_{28} and a thickness d_{28} .

A typical dielectric multilayer film is configured so that a dielectric film having a high refractive index and a dielectric film having a low refractive index are alternately and repeatedly laminated. Thickness of each dielectric film is typically designed to be an integral multiplication of quarter of the oscillation wavelength λ , i.e., $\lambda/4$ in terms of optical length. Therefore, a appropriate film thickness is adjusted according to the refractive index of the dielectric film.

In this embodiment, the high reflective film 20

includes the dielectric film of aluminum oxide (Al_2O_3), the dielectric film of silicon oxide (SiO_2) and the dielectric film of tantalum oxide (Ta_2O_5). Tantalum oxide has characteristics of small changes of both refractive index and film thickness even if temperature is rising by heating, as shown in Fig.2, which is suitable for the dielectric multilayer film.

Next, a specific configuration of the high reflective film 20 will be described hereinafter. Here, the high reflective film 20 formed on a red semiconductor laser with oscillation wavelength $\lambda=660\text{nm}$ will be exemplified. The equivalent refractive index of the laser chip is 3.817.

As shown Fig.3B, the dielectric film 21, i.e., the first layer in contact with the laser chip is formed of aluminum oxide (Al_2O_3) with refractive index $n_{21} = 1.641$, thickness d_{21} of which is designed to be 201.0nm equivalent to $\lambda/2$ in terms of optical length.

The dielectric film 22, i.e., the second layer is formed of silicon oxide (SiO_2) with refractive index $n_{22} = 1.461$, thickness d_{22} of which is designed to be 112.9nm equivalent to $\lambda/4$ in terms of optical length.

The dielectric film 23, i.e., the third layer is formed of tantalum oxide (Ta_2O_5) with refractive index $n_{23} = 2.031$, thickness d_{23} of which is designed to be 81.2nm equivalent to $\lambda/4$ in terms of optical length.

The dielectric film 24, i.e., the fourth layer is formed of silicon oxide (SiO_2) with refractive index $n_{24} = 1.461$, thickness d_{24} of which is designed to be 112.9nm equivalent to $\lambda/4$ in terms of optical length.

5 The dielectric film 25, i.e., the fifth layer is formed of tantalum oxide (Ta_2O_5) with refractive index $n_{25} = 2.031$, thickness d_{25} of which is designed to be 81.2nm equivalent to $\lambda/4$ in terms of optical length.

10 The dielectric film 26, i.e., the sixth layer is formed of silicon oxide (SiO_2) with refractive index $n_{26} = 1.461$, thickness d_{26} of which is designed to be 112.9nm equivalent to $\lambda/4$ in terms of optical length.

15 The dielectric film 27, i.e., the seventh layer is formed of tantalum oxide (Ta_2O_5) with refractive index $n_{27} = 2.031$, thickness d_{27} of which is designed to be 81.2nm equivalent to $\lambda/4$ in terms of optical length.

20 The dielectric film 28, i.e., the eighth layer is formed of silicon oxide (SiO_2) with refractive index $n_{28} = 1.461$, thickness d_{28} of which is designed to be 225.8nm equivalent to $\lambda/2$ in terms of optical length.

Fig.3C is a graph showing wavelength dependency of reflectance of the high reflective film 20 having the above configuration. This graph shows a reflectance of about 86% at the center wavelength $\lambda=660\text{nm}$, where the change of reflectance is small as against the change of oscillation

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wavelength. Therefore, it can be seen that the high reflective film 20 with the above configuration has a stable reflectance even if the oscillation wavelength of the laser varies.

5 Incidentally, the above description exemplifies the high reflective film 20 which includes the multilayered films having three cycles using the repetitious unit of both the single tantalum oxide film for the high refractive index film and the single silicon oxide film for the low refractive index film, and the additive aluminum oxide film
10 for the low refractive index film in contact with the chip and the additive silicon oxide film for the low refractive index film exposed to the atmosphere. The high reflective film 20 may be configured of one to two cycles or four
15 cycles or more using the repetitious unit of both the single tantalum oxide film and the single silicon oxide film to control a desired reflectance. Furthermore, when shifting the center wavelength of the reflectance characteristic from 660nm, measures can be taken by
20 converting the film thickness of each dielectric film to another film thickness in terms of optical length.

 Fig.4 is a graph showing an example of optical output characteristics versus driving current of the semiconductor laser. For a conventional high reflective film, a
25 multilayered dielectric film is configured of the total

five layers, in sequence from the side contact with the laser chip, aluminum oxide (Al_2O_3) film, silicon (Si) film, aluminum oxide (Al_2O_3) film, silicon (Si) film, and aluminum oxide (Al_2O_3) film.

5 This graph shows that the optical outputs of any lasers increase when the driving currents exceed an oscillation threshold current of about 50mA. The optical output of the conventional type sharply declines at driving current of about 240mA, resulting in the COD degradation.

10 On the other hand, in the high reflective films 10 and 20 according to the first and second embodiments, the COD degradation does not take place until driving current of 500mA. It can be seen that the high reflective films 10 and 20 can withstand the optical output approximately 1.7
15 times as high as the conventional high reflective film can.

 The above description exemplifies that the dielectric multilayer film according to the present invention is formed on the rear end face of the laser. The dielectric multilayer film according to the present invention may be
20 formed on the front end face of the laser.

 Although the present invention has been fully described in connection with the preferred embodiments thereof and the accompanying drawings, it is to be noted that various changes and modifications are apparent to
25 those skilled in the art. Such changes and modifications

are to be understood as included within the scope of the present invention as defined by the appended claims unless they depart therefrom.